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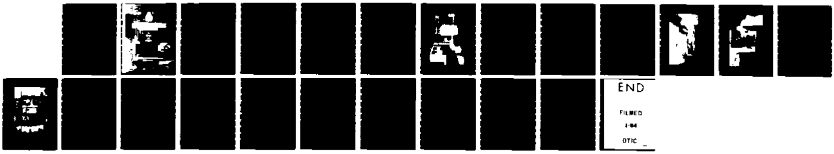

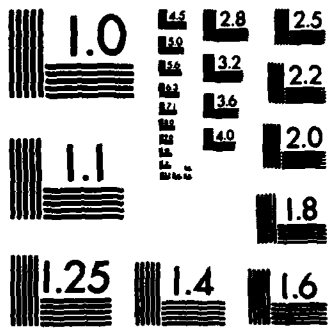

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PROCEDURES FOR STATIC AND CONSTANT-RATE TESTS ON A SINGLE-DEGREE-OF-FREEDOM (SDF) STRAPDOWN GYROSCOPE

by

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ABSTRACT

Test procedures for testing a rate-integrating, Single-Degree-of-Freedom (SDF) strapdown gyroscope are presented. Tests are restricted to static and constant-rate modes in both inertial reference servo and analog-torque-to-balance (ATBL) configurations. Alignment procedures and adopted sign conventions are discussed. Temperature control considerations are described.

RÉSUMÉ

Nous présentons des procédures permettant de tester des gyroscopes auto correcteurs à centrale liée et à 1^{o} de liberté. Les tests sont limités aux modes statistiques et à taux constants, dans les deux configurations suivantes soit: référence inertielle et couple-équilibre analogique (ATBL). Les procédures d'alignement et les signes conventionnels utilisés sont aussi présentés, de mēme que les considérations concernant la régulation thermique.

TABLE OF CONTENTS

1.0 DREO INERTIAL NAVIGATION LABORATORY

The navigation sub-program at DREO was created in 1977 with a mandate to provide technical assistance and advice to DND on all aspects of navigation technology. This has included not only established technologies such as a multitude of radio navigation aids but also satellite position-fixing and strapdown inertial navigation technologies. This latter technology is the basis of the in-house laboratory development at DREO.

The DREO Inertial Navigation Laboratory was developed between 1977 and 1981 as the only complete gyroscope, accelerometer and inertial system test laboratory for the evaluation of strapdown components and systems in Canada. With the aid of a consultant, the laboratory was designed for maximum flexibility; virtually any type of gyroscope can be excited and tested with existing test equipment.

The purpose of such a laboratory is twofold; primarily it provides a test facility for the evaluation of manufacturer's navigation components before procurement of systems but as well it is a flexible, independent facility for experimentation, research and development. More specifically, work within the laboratory has centered upon investigation and characterization of low cost strapdown inertial navigation components and systems. Strapdown technology holds the promise of low cost, long lifetime and ease of maintenance with the mechanical complexity of the traditional gimballed systems being replaced by software computation.

Testing of strapdown gyroscopes is quite different from that of gyroscopes employed on gimballed platforms; a strapdown gyroscope must operate over the entire dynamic range of the vehicle within which it is mounted including not only the possibility of high angular rates but also severe vibration and shock. A photograph of the DREO Gyroscope test station is shown in Figure 1-1. Note that the test platform is a two-axis Goerz motion table which allows both positioning and rate capability about the table axis and positioning capability about the tilt axis. Detailed descriptions and specifications of test station equipment and capabilities are contained in DREO Report No. 895.

Test procedures for characterization and evaluation of strapdown gyroscopes have been developed for use in the DREO laboratory. This report will describe test procedures and data recording as employed in the testing of Single-Degree-of-Freedom (SDF) strapdown gyroscopes only. Specific reference will be made to the Honeywell GG1111 SDF gyro.

2.0 The SINGLE-DEGREE-OF-FREEDOM (SDF) Strapdown (S/D) Gyroscope

Figure 2-1 shows the basic elements of a SDF gyro. The gyro depicted is of the rate-integrating type; that is, the deflection of the gyro element relative to the case is a measure of the integral of the angular velocity of the gyro about its sensitive (input) axis (i.e. change of angular attitude of the instrument). The "damper" in the figure provides the primary restraining torque on the instrument.

Figure 1-1 DREO Gyroscope Test Station

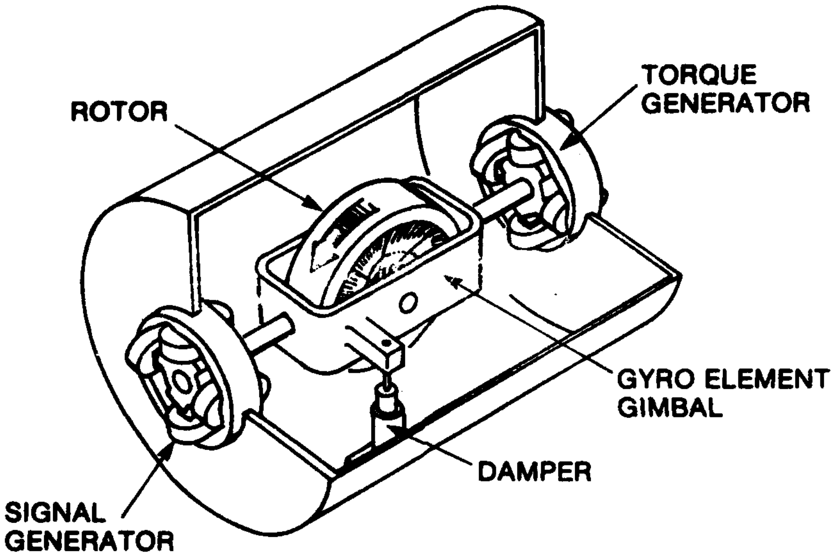

Figure 2-1 Essential elements of a Rate Integrating single-degree -of-freedom (SDF) gyroscope.

Parameter	GG1111(AJ03)
Size	
length	2.38 in.
diameter	1.295 in.
Gimbal Freedom	± 0.35-1.50 deg. max.
Operating Temp	185°F
Spin Motor Power	
Start	5.0 W.max.
Run	4.0 W. max.
Torque Generator	
Sensitivity (STG)	3960 deg/h/ma.
Max. Torquing Rate (continuous)	±220 deg/sec
Linearity	0.1% of full scale (to 100 deg/sec)
Pickoff Sensitivity	68 mV/deg.
Heaters	none
G-Insensitive Drive	
Magnitude	± 50.0 deg/hr
Stability	± 8.0 deg/hr (6 mos)
G-Sensitive Drift	
Magnitude	12.0 deg/hr/g (vector sum)
Stability	17.0 deg/hr/g (vector sum)
G^2-Sensitive Drift	
Magnitude	0.2 deg/hr/g^2(20-2000Hz)
Run-Up Time	15 sec. max (185°F)

Table 2-1 Honeywell GG 1111-Performance Characteristics

The test procedures described in this report were used to test such a rate-integrating SDF gyro. The gyro actually tested was a Honeywell model GG1111 gyro. The performance specifications of this gyro are given in Table 2-1. Note that this is a floated-type, low grade inertial instrument with very high bias and acceleration-sensitive drifts and relatively poor stability. Other instruments in the same class as the GG1111 include the Lear Siegler Model 1903 and Northrop Model GI-G6. Typical applications for this grade of gyroscope include short range missile guidance, attitude heading reference systems and other forms of low-cost inertial guidance.

Although gyroscopes of such low quality are not usually employed as vehicle inertial navigators, it is felt that with proper characterization of the error terms of the instruments, many of the errors can be compensated for in navigation software resulting in large improvements in system performance. The first step in such characterization is the testing of the individual inertial components.

3.0 TEST FIXTURING AND TEMPERATURE CONTROL

For the purposes of laboratory testing, the gyroscope is mounted in a mechanical fixture which permits alignment of the gyroscope with the test table as well as providing a method of heating the gyroscope to its desired operating temperature.

3.1. GYRO ALIGNMENT PROCEDURE

The laboratory motion table is levelled and aligned to within 20 arcseconds of True North. Before testing of the gyroscope can begin, the instrument must be aligned with the table.

For a SDF instrument, alignment consists of:

a) alignment of the Input Axis (IA) about the Output Axis (OA) and

b) alignment of the IA about the Spin Reference Axis (SRA)

The alignment fixture is comprised of two parts. The first is a gyro holding fixture as shown in Figure 3-1. By loosening the front flange, the gyro can be rotated while levelling is accomplished by the three spring-mounted screws. This fixture contains the heaters and temperature sensors as well.

The second portion of the fixture is a three-sided fixture to which the gyro-holding fixture is attached. The three-sided fixture can then be rotated as required to achieve various gyroscope axes orientations. This fixture is shown in Figure 3-2.

To accomplish the alignment, the IA of the gyro is aligned about the OA by spinning the gyro about it's Spin Axis and observing the Signal Generator (SG) Secondary output. The IA is aligned about OA when rotation of the gyro about SRA produces no output. Similarly, to align the IA about the SRA, the gyro is oriented such that it is spun about OA. The IA is aligned

Figure 3-1 GG1111 Gyro Mounted In Alignment Fixture

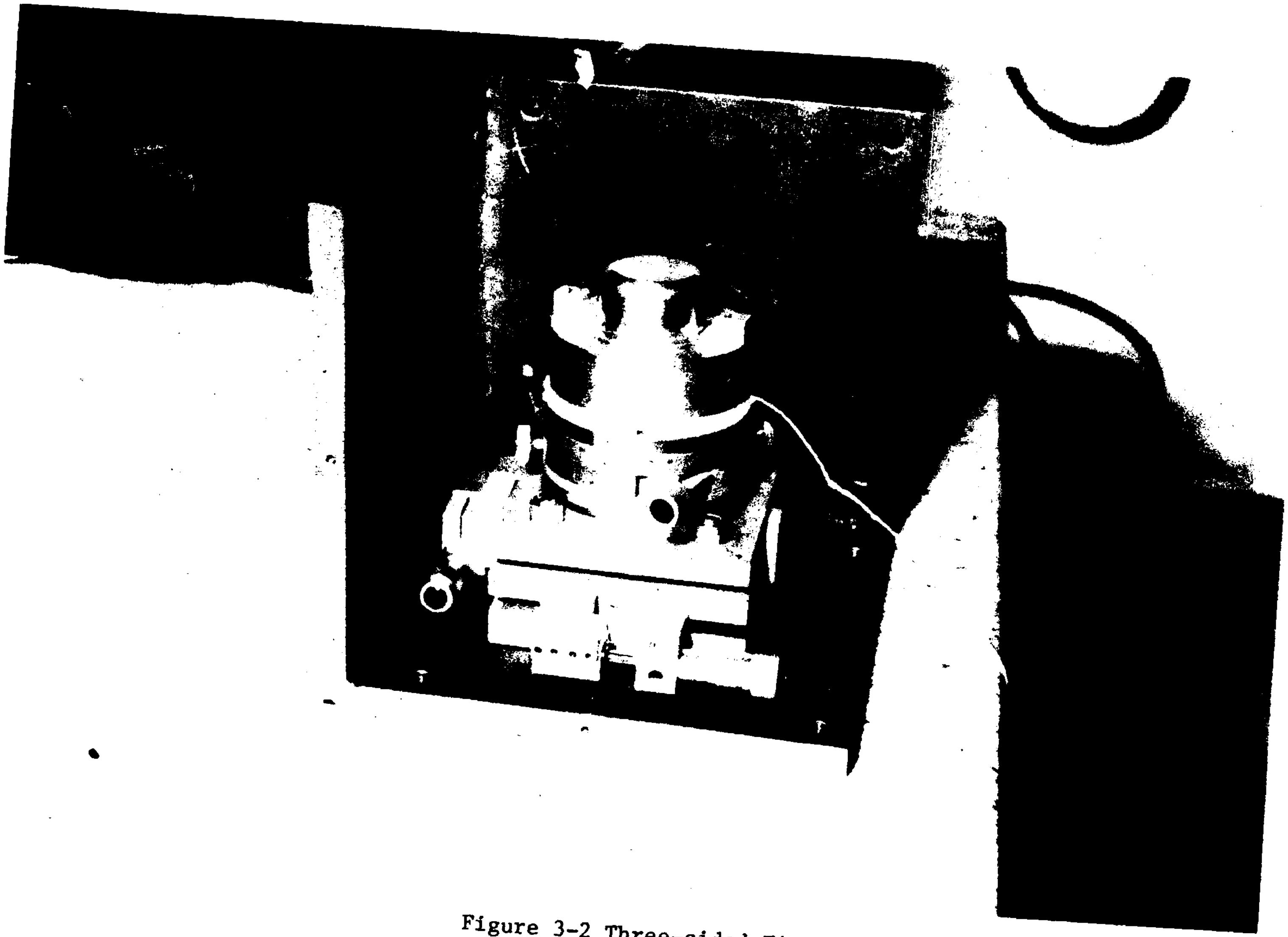

Figure 3-2 Three-sided Fixture

about SRA when rotation of the gyro results in no change in the SG Secondary output.

Using the described fixtures and an oscilloscope, the gyro can be aligned to the motion table within approximately 20 arcseconds.

3.2. GYRO TEMPERATURE CONTROL

The performance of a floated SDF gyro depends greatly upon the control of it's temperature. The Honeywell GG1111 has no internal heaters and must, therefore, be externally heated and controlled. As shown in Figure 3-1, heaters surround the gyroscope at one end. Unfortunately, the design of this fixture does not allow for uniform heating and control of the gyro temperature. As an indication of the type of temperature control obtained with this fixture, several tests were performed and gyro temperatures recorded.

Figure 3-3 shows the gyro mounted on the table top. Note that the three open sides of the three-sided fixture are covered with plexiglass to reduce air currents around the gyroscope and its alignment fixture. Thermistor probes were attached both to the exposed end of the gyro and to the fixture. A temperature gradient of 9 degrees centigrade was noted between the two probes in nearly all gyro orientations. This is a significant gradient implying a very poor thermal environment for the instrument. Evidently, a holding fixture which covered the entire gyro would reduce such gradients. The effects of thermal gradients and instability can cause significant changes in instrument bias drift and some mass unbalance-induced errors. More will be said about testing for the effects of temperature in the next section. An example of a thermally-uniform fixture design is shown in Figure 3-2(mounted in the 3-sided fixture)

4.0 SDF GYRO TEST PROCEDURES

4.1. TEST PHILOSOPHY

As mentioned in Section 2, the testing of inertial instruments permits characterization of the errors within the instrument. In general, manufacturer's tests are limited to only major errors and "lumped" error effects. In actual fact, errors can be individually characterized for specific instruments without great difficulty permitting compensation for many error effects through software algorithms in a navigation system's computer. Evidently, the more error terms that are characterized, the greater the possible navigation system performance improvement. This would imply that proper characterization of low-grade (low-cost) inertial instruments could result in improved low-cost system performance.

The major error terms investigated include both G-Sensitive and G-Insensitive terms; bias drift (BD) and acceleration-sensitive drift about each instrument axis (ADIA, ADSRA and ADOA). In addition, Torque Generator sensitivity and temperature effects are also evaluated.

For all error terms, not only is the magnitude of interest but also stability, repeatability, sensitivity (to temperature or rate changes) and transient effects must be investigated.

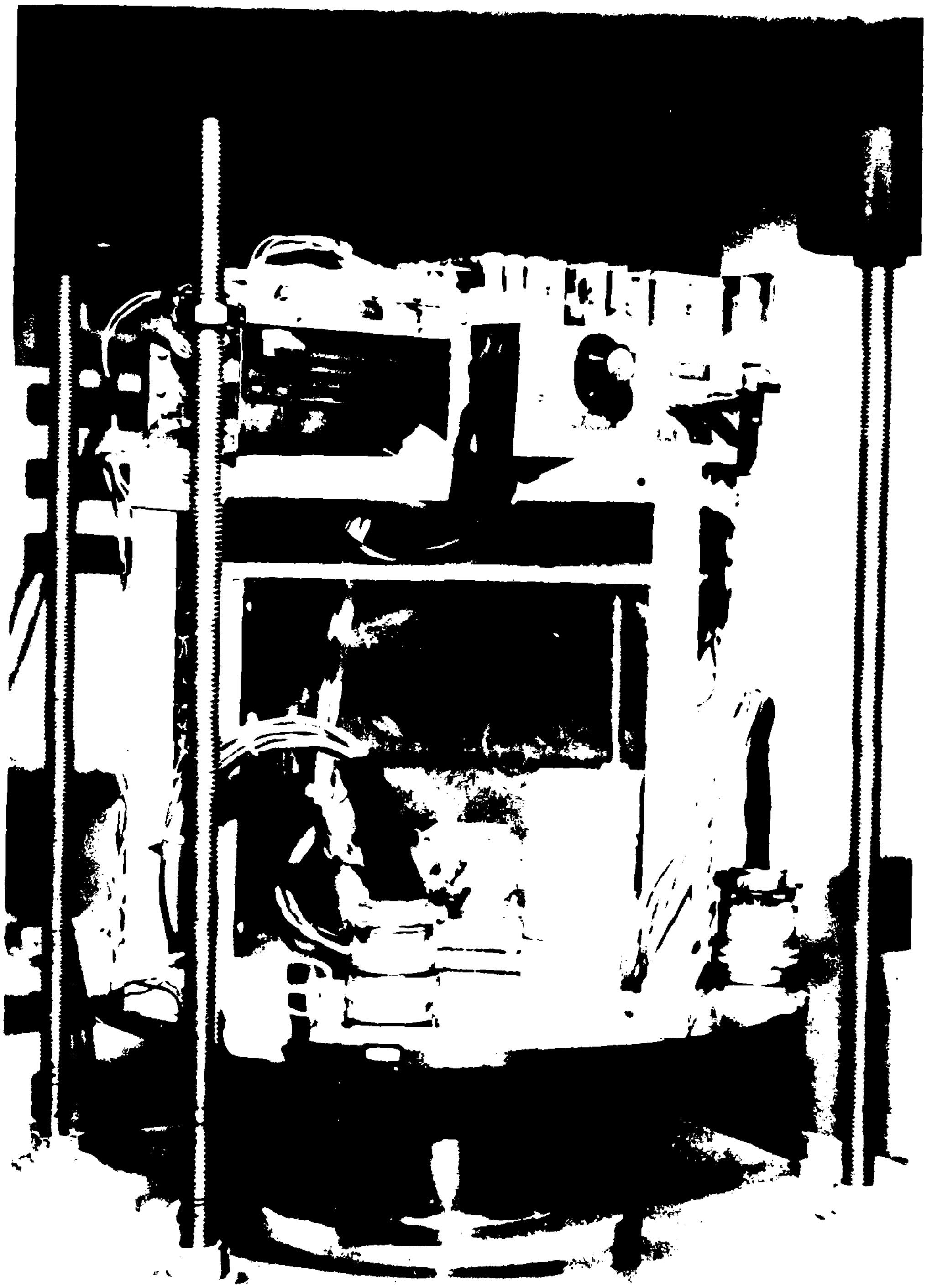

Figure 3-3 Honeywell GG1111 Gyro and Associated Electronics Mounted On The Motion Table

The gyro can be tested in two modes; inertial reference servo mode where the motion table servo loop is used to drive the table to oppose earth rate and gyroscopic drift and torque-to-balance mode whereby the gyro float is nulled by the application of current to the gyro torquer coil by means of an electronic sensing and feedback circuit. Test procedures for both modes are described in the next sections.

4.2. SIGN CONVENTIONS

Before tests can begin, a standard series of sign conventions must be defined and applied to all tests for consistancy.

The following sign conventions were adopted for the tests described in this report:

It is assumed that the instrument drift causes clockwise (CW) rotation of the inertial table top. This is referred to as positive drift.

In general, for IA oriented vertically up,

$$DRIFT = W_{IEV} - (\pm W_T)$$

where W_{IEV} is the local vertical component of earth rate and W_T is the drift rate of the table top.

and for IA oriented horizontal north

$$DRIFT = W_{IEH} - (\pm W_T)$$

where W_{IEH} is the local horizontal component of earth rate.

Therefore, by convention, for IA vertical up we define

DRIFT = BD +ADIA

and for IA horizontal north

SRA up :DRIFT =BD+ADSRA
SRA down:DRIFT =BD-ADSRA
OA up :DRIFT =BD+ADOA
OA down :DRIFT =BD-ADOA

4.3 TEST PROCEDURES

The following sections contain the test procedures for a SDF gyroscope in both inertial reference servo and analog torque-to-balance modes. The tests are broken down into two areas:

a) G-Sensitive and G-Insensitive drift terms (BD, ADIA, ADSRA, ADOA) including magnitude, stability, repeatability and sensitivity to cool-down and temperature variation and

b) Torque Generator (Signal Generator) characteristics including linearity, stability and transient effects due to rate changes.

4.3.1 Inertial Reference Servo Tests

The bias and acceleration-sensitive drift terms can be determined using a 5-position servo test while torque generator characteristics require the application of very precise current inputs to the gyro torquer coil.

4.3.1.1 5-POSITION SERVO TEST

The gyroscope is stabilized at it's nominal operating temperature. The motion table is sequentially oriented into 5 positions such as to isolate each gyroscope axis in turn in the local vertical position:

a) IA vertical up, OA west,
b) IA horizontal north, SRA vertical up,
c) IA horizontal north, SRA vertical down,
d) IA horizontal north, OA vertical up and
e) IA horizontal north, OA vertical down

The drift rate of the table top is sampled for each gyro orientation.

The individual magnitudes of the drift terms BD,ADIA, ADSRA and ADOA are calculated by substituting into and solving the five simultaneous equations previously described under the adopted sign conventions. The terms are expressed in units of deg/hr (for BD) and deg/hr/g (for ADIA, ADSRA and ADOA)

4.3.1.2 DRIFT STABILITY

With the gyroscope stabilized at it's operating temperature, the gyroscope is allowed to drift for 24 hours in servo mode as the drift rate is sampled. This test is performed for each instrument axis:

a) IA vertical up and
b) IA horizontal north

Drift rate is plotted with respect to table angle or time. Drift stability is the peak-to-peak change in drift rate over the entire test period expressed in deg/hr.

4.3.1.3 REPEATABILITY OF BD, ADIA, ADSRA, ADOA

Repeatability of drift term magnitude is shown by repetition of the procedure in section 4.3.1.1.

4.3.1.4 COOL-DOWN SENSITIVITY OF BD AND ADIA

Both bias drift and acceleration-sensitive drift about the input axis (ADIA) are temperature-sensitive terms which change due to heating and cooling of the instrument. The effect is isolated by heating the gyroscope to it's operating temperature, cooling to room temperature and then reheating. A 5-position servo test is then performed to determine changes in BD and ADIA due to cool-down. Shifts of 2 to 10 deg/hr are common in instruments such as the Honeywell GG1111.

4.3.1.5 TEMPERATURE SENSITIVITY OF BD, ADIA, ADSRA AND ADOA

A 5-position servo test is performed on the instrument for several temperature settings both above and below normal instrument operating temperature. The instrument must be allowed to stabilize for several hours after each temperature change to avoid transient effects. BD, ADIA, ADSRA and ADOA are calculated at each temperature setting and plotted. Large changes in each drift term (particularly BD and ADIA) should be expected.

4.3.1.6 TORQUE GENERATOR SENSITIVITY (LINEARITY)

The gyroscope is stabilized at it's operating temperature with the table positioned with IA vertically up in servo mode. A very precise current source is used to apply current to the torquer coil. A range of currents from microamperes to several hundred milliamps (depending on the gyro) is applied in steps in the positive direction followed by the same repetitions in the reverse polarity. Table rate for each torquer current step is recorded, earth rate (a constant) removed and the data plotted. Linearity is expressed as the deviation from perfect linearity as a percentage in ppm over the dynamic range of the instrument.

4.3.1.7 TORQUE GENERATOR SENSITIVITY TO AN IA RATE CHANGE

With the gyroscope stabilized at it's operating temperature and positioned with IA vertically up, a DC current is fed into the torquer coil for five minutes. At the end of this time the input current is removed and the table rate is sampled over a period of several minutes. This data is plotted to show any transient effects due to the sudden rate change. This test is carried out for several different DC current input levels equating to various rates. Drift rate vs time is plotted to show any transients.

This completes the test procedures for the tests performed in the servo mode.

4.3.2 Analog-Torque-to-Balance Loop (ATBL) Tests

In rebalance loop mode, the gyro is subjected to various external rates while the rebalance electronics applies a current to the torque

generator of the instrument to proportionally counteract gyroscope drift and applied input rate. The current applied to the torquer coil by the rebalance electronics is sampled.

4.3.2.1 5 POSITION REBALANCE LOOP TEST

As in the case of servo mode, a 5-position test is performed in rebalance loop mode. In this case, the table top is locked into each of the five gyroscope axes orientations:

a) IA vertical up, OA west,
b) IA horizontal north, SRA vertical up,
c) IA horizontal north, SRA vertical down,
d) IA horizontal north, OA vertical up and
e) IA horizontal north, OA vertical down

The effect of earth rate input and instrument drift is counteracted by a restoring current from the rebalance electronics. The restoring current is sampled and translated to an equivalent drift rate using the nominal sensitivity of the torque generator as a conversion (S_{TG}).

Again the individual magnitudes of BD, ADIA, ADSRA and ADOA are calculated. Comparison of the magnitudes obtained should show close agreement with the results of servo loop tests. Disparity will, ideally, be the result of rebalance electronics imperfections, an effect which must be considered during electronic design for specific instruments.

4.3.2.2 DRIFT STABILITY

With the gyroscope stabilized at its operating temperature and the table locked into the IA vertical up position followed by the IA horizontal north position, the rebalance current to the gyro torquer is sampled for 24 hours in each of three positions:

a) IA vertical up, OA west,
b) IA horizontal north, SRA vertical up and
c) IA horizontal north, OA vertical up

The equivalent drift rate of the instrument is plotted against time. Drift stability is the peak-to-peak change in drift rate over the entire test period. Drift stability should agree with the results of Section 4.3.1.2 (servo mode).

4.3.2.3 REPEATABILITY OF BD, ADIA, ADSRA, ADOA

Repeatability of drift term magnitudes is shown by repetition of the procedure in Section 4.3.2.1.

4.3.2.4 COOL-DOWN SENSITIVITY OF BD AND ADIA

As in Section 4.3.1.4, the effect of cool-down on BD and ADIA can be determined by the performance of a 5-position rebalance loop test after cool-down and reheating of the instrument. Again, results should be

comparable to those in servo mode.

4.3.2.5 TEMPERATURE SENSITIVITY OF BD, ADIA, ADSRA AND ADOA.

As in Section 4.3.1.5, a 5-position servo test is performed for each of several temperature settings both above and below normal instrument operating temperature. The instrument must be allowed to stabilize for several hours after each temperature change to avoid transient effects. BD, ADIA, ADSRA and ADOA are calculated at each temperature setting, plotted and compared to the results obtained in servo mode. Temperature sensitivity can be expressed as drift change per degree temperature change.

4.3.2.6 SCALE FACTOR LINEARITY

The gyroscope is stabilized at normal operating temperature with IA vertically up. Rates in various steps ranging from .01 deg/sec to maximum gyro capability (approx. 200 deg/sec for the GG1111) are applied to the table top. Restoring current to the torquer coil is sampled at each rate. This is done in both directions, earth rate removed from the data and the data is then plotted. Linearity is expressed as the deviation from linearity in ppm over the dynamic range of the instrument. This value should be comparable to that obtained from the servo tests but, again, the effects of electronics non-linearities must be considered.

4.3.2.7 SCALE FACTOR STABILITY

The gyroscope is stabilized at it's operating temperature and oriented with IA vertical up. A low rate is applied to the table top (within the linear portion of the torque generator range). Restoring current to the torque generator is sampled for 24 hours and the resulting Scale Factor is plotted against time. Scale factor stability is the peak-to-peak variation over the 24-hour period.

This completes the test procedures for a SDF strapdown gyroscope in analog-torque-to-balance mode. These same procedures could be used in pulse rebalance mode as well. Details on pulse rebalance electronics and peculiarities in such test procedures are contained in References (1) and (2).

5.0 DATA RECORDING

As noted in the previous sections, the data required for inertial instrument evaluation consists of table rates, time and voltage or current measurements. The recording of this data in the DREO Inertial Laboratory is automated through the use of a PDP-11/03 microprocessor. All measurement instruments are integrated onto an IEEE 488 bus system which permits standard, formatted data transfers.

Data acquisition programs have been written for the various tests previously described and data is automatically recorded on floppy disk and required scaling and calculations are carried out and printed for operator use.

6.0 CONCLUSION

The procedures described in this report have been employed during the testing of several GG1111-class gyroscopes and have resulted in consistent, repeatable results. Specific results of the testing of a Honeywell GG1111 gyro are contained in DREO Report # 895 .

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